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Solar energy in Jordan: current state and prospects

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Abstract

In this paper, the share of solar energy in the energy mix in Jordan for the years 2002 and 2007 is estimated by calculating the energy equivalent of solar energy systems whether utilized or to be utilized. The share of solar energy in the energy mix in Jordan in the year 2002 is estimated to be around 1.7–1.8%. The expected share of solar energy in the total energy mix in the year 2007 is estimated to be around 2.1%. Assuming that the crude oil prices in the year 2007 is going to be 30 US\$ bbl^{-1} (20 Jordan Dinars 'JDs' bbl^{-1}), the cost of required primary energy for Jordan will be around 736 million JDs. Thus the 2.1% share of solar energy would save around 16 million JDs per year of imported energy.
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Keywords: Solar energy; Photovoltaics; Solar water heaters; Jordan

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1. Introduction

Jordan imports all of its necessary petroleum from neighboring countries [1]. On the other hand, Jordan is blessed with huge amounts of oil shale and renewable energy resources, particularly solar and wind energies [2–4]. In order to reduce dependence on the imported oil, Jordan has pursued programs for promoting solar energy involving systematic monitoring and assessment of technological developments combined with the implementation of appropriate technologies, demonstrations and pilot projects [5–10].

In a recent study, only the industrial applications of solar energy in Jordan were assessed and reviewed [11]. The main objectives of this paper are reviewing and assessing the current and future share of various solar energy applications in the over all mix of energy in Jordan, as well as identifying potential areas for utilizing future technologies and recommending future courses of action to encourage the commercial utilization of solar energy technologies.

2. Resource assessment

Since measurements and long-term records of solar radiation data for most parts of Jordan are not available, the existing correlation relations and models are used for estimating and evaluating solar radiation. Good agreement is achieved when the results of such models are compared with some measured data for solar irradiance. Referring to these models and other studies and measurements on radiation as well as to the variation in the topography and climatology of Jordan, the country is divided into five regions [4,12–14].

1. The southern region (29–30.5°N, 35–38°E) represented by the M'aan and Aqaba areas. This region has the highest solar insulation in the country and has the lowest value of diffuse irradiance. In this regard, the annual daily average values of global irradiance are between 6 and 7 kWh/m^2 day, 1.2 and 1.35 kWh/m^2 day for diffuse irradiance and between 4 and 5 kWh/m^2 day for the direct beam component.
2. The eastern region (30.5–32.5°N, 36.5–39°E). This region represents the semi desert (badia) remote areas in the country. Annual daily average values of about 5.0 and 1.5 kWh/m^2 day for global and diffused irradiance respectively are obtained for this region.

3. The middle region (30.5–32°N, 35.5–36.5°E). Compared to other regions, this region has the highest annual daily average values of diffuse irradiance ranging between 1.6 and 1.9 kWh/m^2 day. The global irradiance is about 4.5 kWh/m^2 day in this region.
4. The northern region (32–33°N, 35.5–36.5°E). In this region the annual daily average value of global irradiance is about 5.5 kWh/m^2 day, and between 1.45 and 1.55 kWh/m^2 day for diffuse solar irradiance.
5. The western region (30.5–33°N, 35–35.5°E). This region represents the Jordan Rift Valley areas. The elevation of these areas is below the sea level (from 170 m at Baqura to 250 m at Ghor Safi). The values of diffused solar irradiance over this region have a high estimate, compared to other regions (1.6–1.8 kWh/m^2 day). Annual daily average values of global irradiance are between 4.5 and 5 kWh/m^2 day.

In general, the abundance of solar energy in Jordan is evident from the annual daily average of global solar irradiance, which ranges between 5 and 7 kWh/m^2 day on horizontal surfaces. This corresponds to a total annual value of 1600–2300 kWh/m^2 year.

3. Applications

3.1. Solar water heaters (SWHs)

The SWH industry in Jordan was first established in 1973. A typical family size SWH unit consists of 3.5–4 m^2 of solar collectors areas and a 150–200 l hot storage tank.

Due to high and reliable solar irradiance of about 5.5 kWh/m^2 day a typical Jordanian SWH with 4 m^2 net area and 25% average system efficiency over the life time has the potential to produce around 150 l of hot water at 55 °C per day for about 330 sunny days per year [15]. Almost 110,000 SWH units have been installed in Jordan since 1973. This represents a 26% penetration rate since the number of occupied housing units is approximately 420,000. This rate is influenced by several technical and non-technical factors such as the following.

- Selection and treatment of materials used in the manufacturing of SWH. This situation drastically reduces the economic viability and performance of SWH systems over their lifetime.
- Space availability on roofs especially in high-rise buildings.
- Lack of public awareness of the benefits of using SWH systems, and of the maintenance and monitoring procedures.
- The unavailability of credit schemes, especially for the low-income groups, in order to have a SWH system with soft payments.

Currently the Royal Scientific Society (RSS) has a SWH laboratory for simulation of solar radiation, quality control, calibration and determination of performance behavior of SWH [10]. This will assure the quality and reliability of SWH and protect both the consumer and manufacturer.

3.2. Photovoltaics (PV)

Tables 1 and 2 [16] show the PV systems installed by the RSS. The sum of their peak power reaches 82 kWp. Around 18 kWp are also installed for other purposes. Under the solar conditions and an average PV efficiency of 10%, each kWp gives an average of 5 kWh day^{-1}. Thus the total yearly energy output of PV systems in Jordan is about 182.5 MWh.

4. Share of the utilized solar energy resources in the energy mix in the year 2002

4.1. SWHs

In order to calculate the ton of oil equivalent (toe) of SWH the following assumptions were been made.

- Number of operating SWH is 110 000 unit (N).
- Average family size is 6.7 persons (AFS).

Table 1
PV pumping projects in Jordan

No.	Well name	PV efficiency(%)	PV output (Wp)	Well characteristics					
				Depth (m)	Static level (m)	Dynamic level (m)	Output volume ($m^3\ h^{-1}$)	Pumping head(m)	Daily output (m^3)
1	Umari	7.70	1613		20.50	36017	9.00	27.00	40.00
2	El-Hazeem 1	12.00	1759		12.40	12.64	24.00	19.00	55.00
3	El-Hazeem 2	9.80	1656		12.40	13.64	24.00	19.00	58.00
4	Jafr 1	7.70	1344	50	16.00	21.50	20.00	21.00	41.00
5	Rahmeh	12.30	2226	45	22.77	25.00	50.00	35.00	40.00
6	Alshomari 1	7.70	2150.4	103	0.95	12.35	75.00	12.00	60.00
7	Alshomari 2	7.70	2150.4	103	0.95	12.35	75.00	12.00	60.00
8	Tal Hassan	7.82	5880	174	69.55	81.72	106.00	75.00	40.00
9	Wadi Eluttom 1	10.00	1800	550	39.00	44.48	106.00	51.00	—
10	Wadi Eluttom 2	10.00	3600	550	39.00	44.48	106.00	51.00	—
11	Wadi El ritem	10.00	4500	236	19.60	26.98	54.00	30.00	99.00
12	Hazeem ElDahk	11.10	4500	53	16.00	22.25	67.00	30.00	50.00
13	Sarq Elhasa	11.10	6300	250	69.80	79.90	88.00	81.00	47.00
14	Umrug 2	11.10	4500	114	40.00	42.70	48.00	48.00	54.00
15	Fidan 6	11.10	4200	180	38.00	61.40	32.00	53.00	45.00
16	Breekah	10.00	2800	200	5.00	10.00	19.00	19.50	90.00
17	Jafr 2	10.00	2800	50	16.50	21.50	20.00	27.00	33.00
18	Jafr 7	10.00	4200	70	17.00	55.00	20.00	45.00	57.00
Total			57978						869.0[a]

[a] Excluding the daily output of Eluttom 1 and 2 wells.

Table 2
PV systems installed by RSS in Jordan (water pumping is excluded)

No.	Town or village	Project name	Peak power (Wp)
1	Qater	Teachers' residence	106.0
2	Rahmeh	Clinic	464.4
3	Rahmeh	Mosque	120.0
4	Rahmeh	Non directional radiobecon	2161.5
5	Risheh	Clinic	3072.0
6	Risheh	Teachers' residence	153.6
7	Risheh	New mosque	120.0
8	Risheh	Old mosque	76.8
9	Risheh	Non directional radiobecon	2161.5
10	Ber Mad	Clinic	537.6
11	Um Maltha	Potash relay station	2182.0
12	Gregrah	New clinic	1344.0
13	Gregrah	Teachers' residence (female)	100.0
14	Gregrah	Teachers' residence (male)	150.0
15	Gregrah	Head master's residence	100.0
16	Ma'mora	Clinic	1072.0
17	Gohr Safi	Potash harvesting engines	364.8
18	Fian	Phosphate relay station	1760.0
19	King Tala dam		76.8
20	Tal Hassan		7840.0
Total			23962.2

- Efficiency of the SWH system is 25% (E).
- Average daily solar radiation is 5.5 kWh m^{-2} (SR).
- Temperature difference is 40 °C (from 15 °C to 55 °C) (Δt).
- To produce 1 kWh, 275×10^{-6} (toe) fuel is needed (SC).
- Typical area of SWH system is 4 m^2 (A).
- Number of sunny days per year is 330 (NS).
- Specific heat of water is 1 Kcal lit^{-1} $°C^{-1}$ (CP).
- Gross of heating value of heavy fuel is 10 000 Kcal kg^{-1} (H).
- Typical boiler efficiency is 50% (P).
- Daily hot water consumption is 30 lit $person^{-1}$ (AHW).

The solar energy equivalent (SEE) can be calculated using the following formulae:

$$\begin{aligned}\mathrm{SEE} &= N \times A \times \mathrm{SR} \times \mathrm{NS} \times E \\ &= 110\,000 \times 4\ \mathrm{m}^2 \times 5.5\ \mathrm{kWh\ m}^{-2} \times 275 \times 10^{-6}\ \mathrm{toe\ kWh}^{-1} \times 330\ \mathrm{days} \\ &\quad \times 0.25 \\ &= 55\,000\ \mathrm{toe} \qquad (1)\end{aligned}$$

Table 3
Solar energy share in the total energy mix in the year 2002

No.	Type	Energy equivalent (ttoe)	Share (%)
1	SWH	55–58.3	1.68–1.78
2	PV systems	0.051	0.0016
Total		55.051–58.351	1.6816–1.7816

or

$$\begin{aligned}\text{SEE} &= \left[\frac{\text{AFS} \times \text{AHW} \times \Delta t \times \text{CP}}{p \times H}\right] \times \text{NS} \times N \\ &= \left[\frac{6.7\ \text{person} \times 30\ \text{lit person}^{-1}\ \text{day}^{-1} \times 40\ ^{\circ}\text{C} \times 1\ \text{Kcal lit}^{-1}\ ^{\circ}C^{-1}}{0.5 \times 10^{7}\ \text{kcal toe}}\right] \\ &\quad \times 330\ \text{day year}^{-1} \times 110\,000 \\ &= 58\,300\ \text{toe.}\end{aligned} \qquad (2)$$

4.2. PV

The energy output is 182.5 MWh. Assuming that each kWh needs 265 g of fuel to be produced, the energy equivalent is

$$\text{PV} = 182.5 \times 10^{3}\ \text{kWh} \times 275 \times 10^{-6}\ \text{toe kWh}^{-1} = 51\ \text{toe.}$$

Table 3 shows the energy equivalent of the utilized solar energy resources (in the year 2002), and their share in the primary energy consumed in Jordan which was equivalent to 3275 ttoe.

5. Future utilization of solar energy technologies

5.1. SWHs

In order to understand the future potential contribution of SWHs, it is required that an estimate of the potential for the further technology development be prepared and the cost for such development be estimated. The current status of SWH in Jordan is a good starting point for future tasks and developments. Jordan is blessed with high potential solar energy. The rate of penetration of SWH has been steadily increasing to about 26% in 2002. A further increase of SWH penetration will depend on the ability to improve the durability, performance and the local manufacturing capabilities of SWH. Moreover, the availability of credit schemes (e.g solar fund) will enable the low-income classes to pay for the relatively high initial cost and the installation of SWH. The availability of the above conditions will increase the penetration rate up to 35% by the year 2007. This would increase the annual savings of oil and foreign currency and further improve the security of

Table 4
Expected share of solar energy in the total energy mix in the year 2007

No.	Type	Energy equivalent (ttoe)	Share(%)
1	Primary energy demand	5100	100
2	SWH	109	2.13
3	PV systems	0.154	0.003

energy supply. A range of 106–112 ttoe will be saved and further employment could be created.

5.2. PVs

While Jordan has a high potential in terms of solar radiation, the utilization of PVs does not depend only on solar radiation, but also on many factors, especially the PV price development. It is expected that the total installed capacity of PV systems will be around 300 kWp by the year 2007 based on RSS investigations [16]. This is equivalent to 550 MWh.

6. Expected share of solar energy resources in the energy mix in the year 2007

In order to estimate the expected share of solar energy in the energy mix it's essential to project primary energy demand. We'll assume that the growth rate of primary energy demand up to the year 2007 will be high. This assumption could be justified by the following reasons:

1. Prices of energy will not change.
2. Income levels will improve due to better economic conditions (more investment programs, particularly, in the industrial sector).

This will result in an annual growth rate of about 5%.

The expected share of solar energy in the energy mix in the year 2007 can be calculated using the estimated future potential of solar energy in it's energy equivalent together with the projected primary energy demand in the year 2007. Table 4 summarizes these results.

7. Conclusions

The solar energy share in the total energy mix in Jordan in the year 2002 was in the range of 1.7–1.8%. The expected solar energy share in the total energy mix in Jordan by the year 2007 is estimated to be 2.1%. Assuming that the crude oil prices in the year 2007 is going to be 30 US\$ bbl^{-1} (20 Jordan Dinars 'JDs' bbl^{-1}) the cost of required primary energy will be around 736 million JDs. Thus the 2.1% share of solar energy would save around 16 million JDs per year of imported energy.

These results show that Jordan need to begin to rely more on solar energy in order to reduce the dependence on imported expensive sources of energy. Therefore, we recommend that government activities on solar energy should fall into the following general categories:

1. Direct funding of research, development and demonstration projects.
2. Development of institutional framework to facilitate the use of solar energy (e.g. legislation, regulation).
3. Measures to improve technical performance and economic competitiveness of solar energy technologies (e.g. through proper standards and incentives).

It's also recommended that detailed analysis on the following aspects should be carried out:

1. Problems and barriers affecting the utilization of solar water heaters in Jordan and suggested solutions.
2. Problems and barriers affecting the contribution of the private sector in investing in solar energy systems in Jordan and suggested solutions.

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